

IN ORBIT DEGRADATION OF EUV OPTICAL COMPONENTS
IN THE WAVELENGTH RANGE 10-40 nm
AO 138-3

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ABSTRACT

A complement of EUV optical components, including mirrors and thin film filters, has been flown as part of LDEF AO 138-3. The most original amongst these components were multilayered interference reflectors for the 10-40 nm wavelength range. Very moderate degradation has been observed for those components which were exposed to the sun. The degradation is compatible with the deposition of a few nanometers of absorbing material on the surface of the samples.

I] INTRODUCTION

In preparation for the SOHO mission planned by NASA / ESA for launch in 1995, we placed test samples of optical components to be used by the Extreme Ultraviolet Imaging Telescope (EIT) on board LDEF¹. These components include thin film filters used for visible light rejection, and a new type of optical reflectors developed for the EUV since 1975^{2 3}. These reflectors consist of a periodic stack of multilayered thin films, deposited on glass substrates. They operate by building up reflectivity from constructive interference of individual beams reflected at the interface between successive highly and weakly absorbing materials. The layer thicknesses are a fraction of the wavelength of the light beam to be reflected so that the period of the structure is $\lambda/2$ (λ being the operating wavelength). We placed samples of such mirrors in the LDEF in order to evaluate the effect of thermal cycling, and surface contamination in low Earth orbit.

II] EXPERIMENTAL PROCEDURE

The samples were produced by electron beam vacuum deposition at Institut d'Optique (IOTA). Their reflectivity was measured at the synchrotron radiation source ACO of LURE (Université d'Orsay). Two lots of samples were placed in one of the FRECOPA containers for launch on board LDEF. This container was vacuum tight and filled with dry nitrogen at 10 mbar pressure several months before launch on the Space Shuttle. The pressure within the container was monitored until very close to the launch date, so that by extrapolation it was certain that the samples had been exposed only to dry nitrogen before deployment. The container was opened several days after the LDEF had separated from the Shuttle. After seven months in orbit the container was again closed under high vacuum conditions. Seven years later this container and the samples were returned to ground. After two months of spacecraft processing, it was found that the pressure in this container was still very low (of the order of $2 \cdot 10^{-3}$ mbar) providing evidence that the samples had been very well protected during recovery and the long period in orbit. Meanwhile, many things had happened on the ground, including the closure of the ACO facility which had been used to measure the optical properties before launch. The flight samples were again stored for several years under high vacuum in their container which was evacuated by vacuum ion pumps. Spare components in a spare container have been kept on ground in the same high vacuum conditions. Using a new facility for the optical test in the 10-150 nm wavelength range, which recently became

operational on the new SUPER-ACO synchrotron machine, it has been possible to reevaluate all these multilayered mirrors nearly 10 years after they were produced. The components which were exposed to the low Earth orbit space environment on board LDEF consisted of two identical lots, the first being exposed to the sun, while the second was kept in the shade and never received solar light. Direct impingement of atmospheric particles (atomic oxygen...) would only have been possible for the lot exposed to the sun. However the FRECOPA container was placed in the wake of the LDEF spacecraft so that bombardment by atomic oxygen was probably minimal in a situation more reminiscent of what is expected for the SOHO spacecraft, at the L1 Lagrangian point between the earth and the sun (1.5 million kilometers away from the earth).

III] RESULTS

We present data concerning the normal incidence reflectivity of the mirror samples in the wavelength range for which they were designed.

The measurements were obtained using a classical reflectometer in which rotation of the detector around the sample makes the measurement of the intensity of the incident and reflected light beam alternatively possible within the source stability time span. The wavelength of the incident light beam could be varied using a grazing incidence monochromator illuminated by the synchrotron radiation continuous spectrum from the positron storage ring. The spectral resolution of the monochromator is 0.2 nm, and a useful light beam can be produced in the 10-150 nm range.

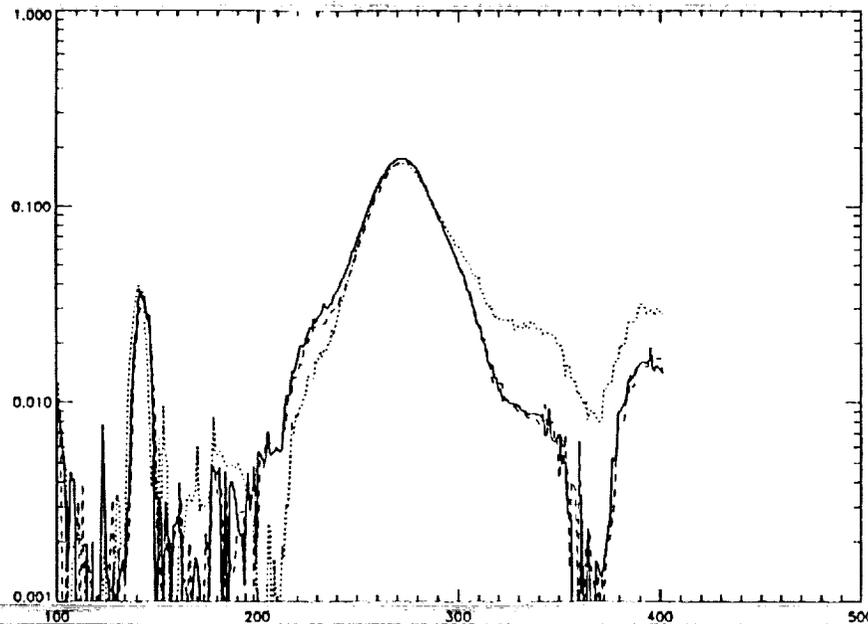


Fig.1: Reflectivity Measurements of Si / WRe multilayers vs. Wavelength (Å). Detector is an Al/Al₂O₃ NIST photocathode. Plain line (a) is a 'reserve' sample, dashed line (b) is a 'shadow' sample, and dotted line (c) is an 'exposed to the sunlight' sample.

The reflectivity curves measured in the conditions close to normal incidence (10 degrees) are shown in figure 1 (a, b, c) for samples of Si / WRe multilayers manufactured simultaneously. Two Bragg peaks corresponding to the first and second order interference standing waves in the multilayered stack can be observed in the range 10-40 nm corresponding to the 15 nm period of the metallic structure. We notice that the peak reflectivities are consistent with those which were measured before flight (1), i.e. in the range

10-15%. We have more confidence in comparative data obtained with the same equipment at the same time rather than in comparison between measurements made 10 years apart with completely different equipment; thus interpretation should rather concentrate on the comparison between samples a, b and c which were respectively kept on ground under vacuum (a), exposed to space in the shadow (b), and exposed to solar light and space environment for a considerable period of time (c), (several months if we consider that only one third of the time was spent during night on the orbit, and another fraction with inappropriate orientation of the LDEF). We notice that the positions of the reflection peaks have not changed, which shows that the geometrical periodicity of the structure has not changed under moderate but persistent thermal cycling. The efficiency of the mirrors has remained quite high at the nominal wavelength with a relative decrease of less than 10 % for the mirror exposed to sunlight. However, we find that the rejection of the light around 35 nm for this mirror has noticeably degraded which means that the most exposed mirror has become slightly less selective.

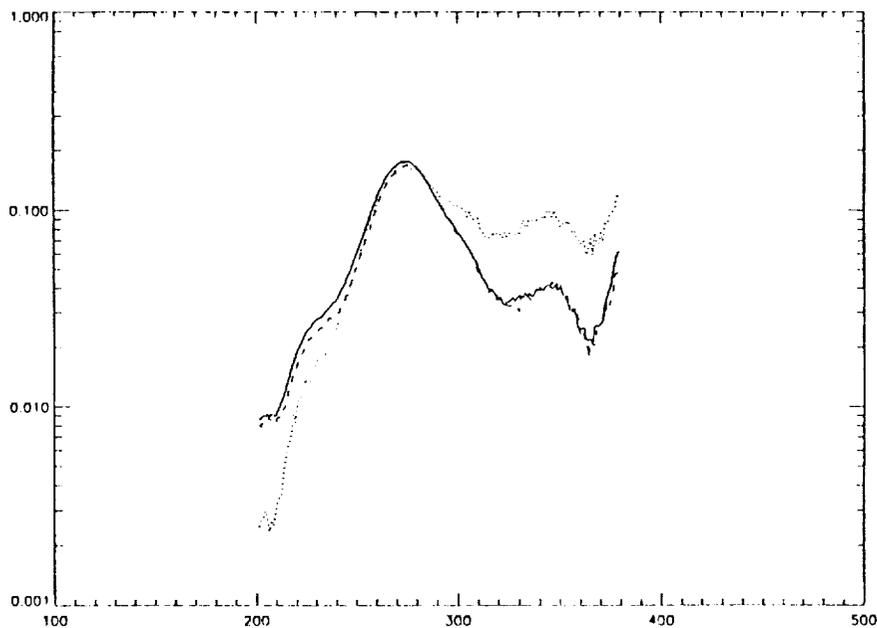


Fig 2 : Reflectivity Measurements of Si / WRe multilayers vs.Wavelength (Å). Detector is a channeltron. Plain line (a) is a 'reserve' sample, dashed line (b) is a 'shadow' sample, and dotted line (c) is an 'exposed to the sun light' sample.

Measuring this effect has been rather difficult however because of the low reflectivity involved. Our standard detector is an NBS windowless photodiode which exhibits a good linearity and dynamics, but whose reading is prone to inaccuracy at low flux level due to the drift of the electrometer in the range 10^{-14} amps. Better measurements above 20 nm were obtained using a channeltron detector behind an aluminum filter used to reduce the photon flux and suppress possible second order contributions from wavelengths shorter than 17 nm for measurements around 30 nm (see fig.2 a, b, c). The overall properties of the interference mirrors have been fairly well preserved, which is noticeable and encouraging for this wavelength range. The multilayered mirrors are in general much less sensitive to contamination than classical bulk material mirrors. This can be understood if one recalls that classical mirrors do not work well in the 10-40 nm range because the bulk absorption in the material occurs at a depth greater than the EUV wavelength: low contrast leads to low reflectivity. Deposition of a contaminant usually decreases the contrast at the transition between the vacuum and the mirror, and so the reflectivity diminishes still more. On the

contrary, in the case of a multilayered mirror, all layers participate in the reflectivity, and a degradation of the top layer has smaller consequences within the nominal band pass. On the other hand the occurrence of a region of minimum reflectivity at wavelenths longer than the main reflectivity peak for the multilayers is due to destructive interferences between the front surface and the deeper layers. Destroying the front surface leads to a less effective rejection of the reflected light in this region.

IV] INTERPRETATION OF THE RESULTS

The mirrors consist in 6 periods of 5nm WRe, and 10 nm Si. We can compute the theoretical reflectivity of a mirror easily, but a fit to real data is rather complex given the large number of possible parameters . We discuss only crude models where two paramaters are deemed sufficient to describe qualitatively the main observations. Thus we introduce a roughness parameter of 1.2 nm rms to explain the slightly reduced reflectivity (compared to a perfect mirror) in the first order peak, and the observed ratio of the first to second order peaks (see fig. 3).

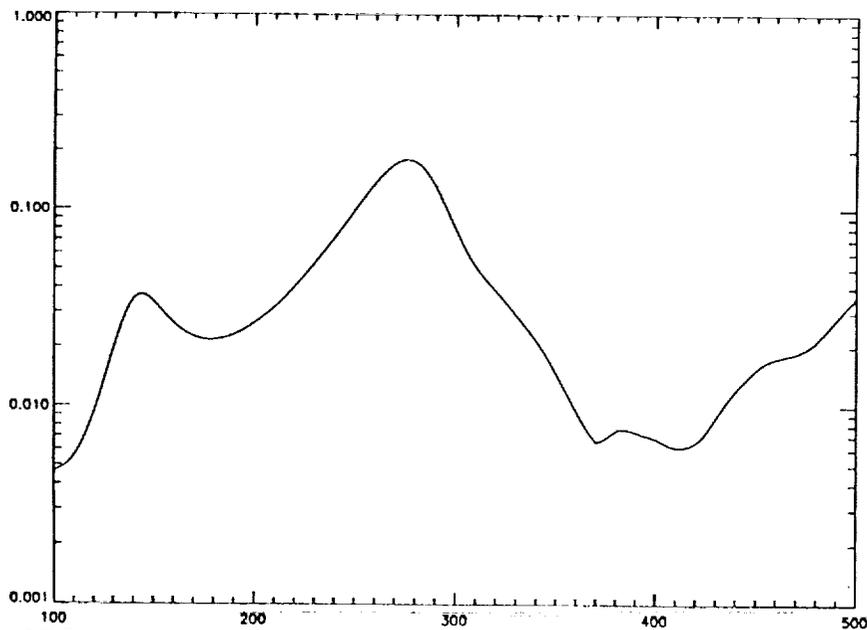


Fig.3 : Reflectivity Model for Si / Re multilayers vs.Wavelength (Å).

The sun-exposed mirror results can then be explained by a contamination layer on top of the initial structure. We tested two possible contaminants : namely pure carbon and silicon oxide, which could represent, with some likelihood, what may be deposited in flight via photochemical reactions involving hydrocarbons and silicon products. We find that no more than 3 nm of contaminating carbon are necessary to explain the observations (see fig.4)

Optical measurements alone cannot discriminate between every possible composition of the deposited contaminant (see fig.5 which compares the effect of carbon and silicon dioxide). It would be necessary to use sensitive surface microanalysis methods in order to measure in more detail the very thin layer, which we believe has been deposited.

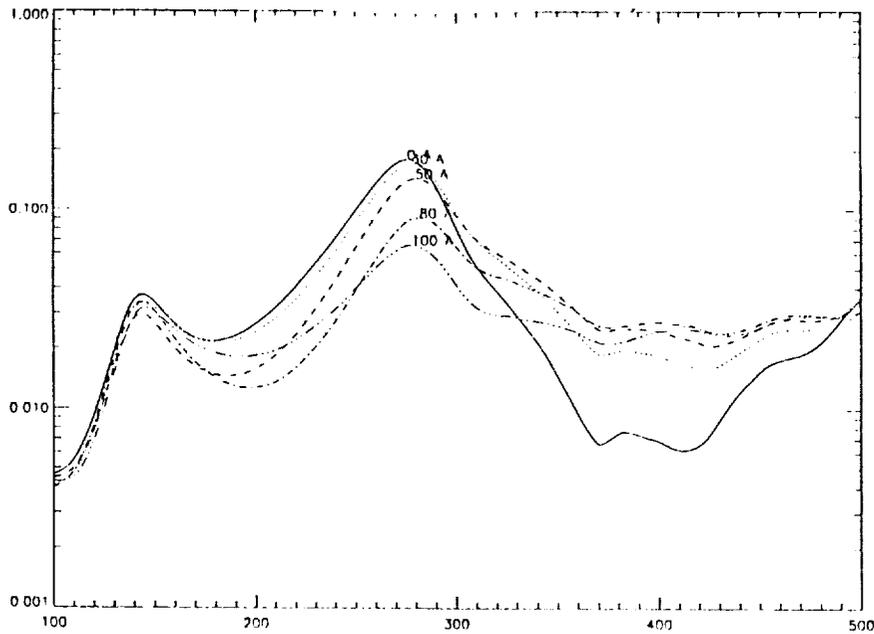


Fig.4 : Reflectivity Model for Si / Re multilayers vs.Wavelength (Å) ; Effect of different thicknesses of carbon as a contaminant (0, 30, 50, 80, and 100 Ångströms).

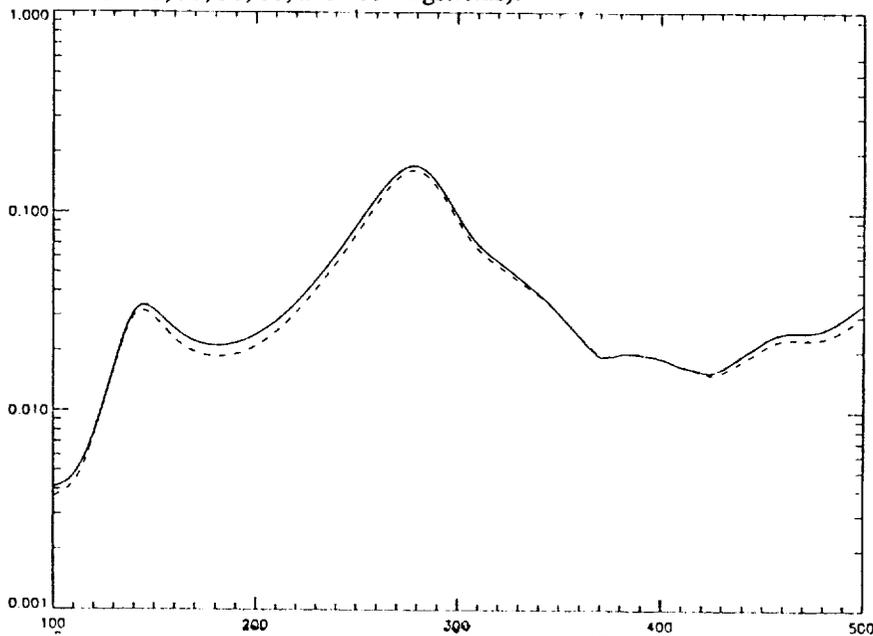


Fig.5 : Reflectivity Model for Si / Re multilayers vs. Wavelength (Å). Comparison of the effect of 30 Å of Carbon (plain line), or 30 Å of SiO₂ (dashed line).

VJ CONCLUSION

We have shown that multilayer coated mirrors for the EUV wavelength range are not too sensitive to contamination in orbit and can effectively be protected by careful handling. In the worst case observed, which involves solar illumination, only 3 nm of contaminant were probably present after seven month exposition in space. The effect of such a contamination on the optical properties of multilayers is acceptable. This low contamination level has been obtained using rather straightforward but stringent handling procedures which involve the control of the ambient atmosphere by a vacuum tight vessel during storage and space launch.

VI] ACKNOWLEDGEMENTS

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¹ DELABOUDINIÈRE J.P., CHAUVINEAU J.P., MARIOGE J.P., (1985) SPIE Proc. 563, p.44

² SPILLER E., (1976) Applied Optics 16, 89

³ VINOGRADOV A.V., ZELDOVICH B.Ya, (1977) Applied Optics 16, 89